

Tissue-engineered Minimalistic Reconstruction of a Severely Crushed Fingertip.

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Abstract

The goals of treatment for fingertip injuries are maximising digital length, tactile sensation, pulp padding, and fingertip appearance while minimising complications like infection and amputation. Currently, terminalisation, healing by secondary intention, and flap surgeries are widely used for crushing fingertip injuries, but they have their own set of issues and limitations. We present a tissue-engineered method by combining platelet-rich fibrin injections with stacked-up layers of synthetic biodegradable temporising matrix to treat a severely crushed fingertip. This novel therapy minimised reconstructions while successfully regenerating new soft-tissues. Soft-tissue regeneration within the stacked-up biodegradable matrix achieved adequate volume, sensation, function, and mobility of the newly reconstructed fingertip while maintaining its skeletal length. Notably, the regenerated fingertip allowed the patient to resume work normally as a busy software engineer. Thus, minimalistic fingertip reconstruction not only prevented a disability, but also served as a viable alternative to major reconstructive surgeries.

Keywords: Fingertip injury; Hand injury; Tissue reconstruction; Platelet-rich plasma; Biodegradable temporising matrix.

Introduction

Crushing fingertip injuries are common throughout the world and frequently present as emergencies. The main goals of treating such injuries are to maintain functional length, adequate sensation, durable skin cover, and early finger mobilisation. Currently, surgeons perform various reconstructive flap surgeries by mobilising skin and soft-tissues from the same finger, adjacent finger, palm, toes, abdomen, or groin^[1]. Healing by secondary intention, including the use of semioclusive dressings, is an attractive alternative^[2]. Although biomaterials were previously described for reconstruction, their use was restricted due to certain limitations^[3].

Aims

To regenerate sufficient soft-tissues to restore the volume, sensation, and function of a severely crushed fingertip.

Case presentation

A 28-year-old male software engineer presented to our emergency department with a severely crushed right-dominant ring finger following an industrial accident. The palmar soft-tissues and distal phalangeal tuft were destroyed completely, leaving the remaining distal phalanx and distal interphalangeal joint exposed (Figure 1A). The nail plate was avulsed from the traumatised nail bed underneath (Figure 1B), which separated from the distal phalangeal bone below due to the severity of the injury (Figure 1C). The patient was advised on various reconstructive options. However, he refused invasive surgeries in favour of a regenerative approach involving short procedures and minimal hospitalisation.

To develop new granulations over exposed bone, platelet-rich fibrin (PRF) injections were prepared by centrifuging venous blood in glass vials without anticoagulants at 700 rpm for 3 minutes. After injecting

PRF into the wound, the exposed bone was covered with a PRF membrane prepared after 12-minute centrifugation (Figure 1D). Once granulations engulfed the bone (Figure 1E), a bilaminar biodegradable temporising matrix (BTM, PolyNovo Biomaterials Pty Ltd, Port Melbourne, VIC, Australia) was placed over the wound and sutured close (Figure 1F). After 6 weeks, delaminating BTM's outer membrane revealed good volume over the sides. However, the main soft-tissue bulk that forms the pulp was conspicuously absent. Instead, the bone was covered by an unsatisfactorily thin epithelialized layer (Figure 1G). Meanwhile, dorsally, the traumatised nail bed healed satisfactorily (Figure 1H).

A novel procedure was then performed to volumize the finger pulp. The epithelialized layer was first tangentially excised to reveal the underlying granulations (Figure 2A). The absorbable inner foam-matrix of BTM was separated from the non-absorbable outer lamina (Figure 2B), and double-stacked over the granulations (Figure 2C). Finally, bilaminar BTM was applied on the stacked layers of foam-matrix on the palmar aspect as well as the nail bed (Figure 2D-E). PRF was injected around the wound margins, and the injections were repeated weekly for the next 1 month. During the following months, soft-tissues developed well inside the stacked BTM, forming both the finger pulp and the nail (Figure 2F-I).

While reviewing at 6-monthly postoperative follow-up, the regenerated finger appeared mostly identical to the opposite side. It was fully functional and looked a lot like the opposite finger, with well-developed nails. However, due to the loss of bony length caused by the initial trauma, it was shortened at the tip, resulting in the nail hooking forwards and medially (Figure 2J-L). Functionally, the patient performed all normal and strenuous activities successfully. In addition, the regenerated finger pulp enabled him to type normally on any computer keyboard and develop software to support his livelihood. Patient-reported satisfaction was measured on a 1-10 visual analogue scale, with the patient scoring a perfect 10/10 for this treatment.



Figure 1 shows a severely crushing injury to the right-dominant ring finger and the results of its initial treatment. (A) On the palmar aspect, complete loss of pulp and soft tissues exposed the distal phalanx (white arrow) and distal interphalangeal joint (red arrow). (B) Avulsion of the nail plate from the underlying sterile matrix (nail bed) was visible. (C) The distal phalangeal tuft was destroyed, shortening the bone (white arrow) that separated from the sterile matrix (yellow arrow). (D) PRF was injected into the surrounding soft tissues, followed by the application of a whitish PRF membrane over the bone. (E) Within a few days, newly regenerated tissues had almost completely covered the bone. (F) The entire wound was sutured with synthetic bilaminar biodegradable temporising matrix (BTM). (G) Six weeks later, there was good volume along the sides of the finger. However, the bone was only covered by thin epithelialized tissues, and palmar soft tissue development was inadequate. (H) In the meantime, the repaired sterile matrix healed well dorsally.



Figure 2 illustrates a novel tissue-engineered method for regenerating an injured fingertip. (A) The underlying granulations covering the distal phalanx were revealed after the superficial flimsy tissues were de-epithelialized. (B) BTM's inner absorbable foam matrix was separated from the outer non-absorbable lamina. (C) The granulations were covered with two layers of inner foam matrix. (D) The palmar wound was finally sutured closed and covered with bilaminate BTM. (E) Dorsally, bilaminate BTM also covered the sterile matrix. (F) Palmar soft tissue regeneration was found to be adequate 6 weeks postoperatively. (G) The nail plate formed well, but with ridges. (H) Finger pulp development appeared adequate 3 months after surgery. (I) The ridges vanished, leaving the nail plate looking normal. (J) A 6-month postoperative review revealed sufficient finger length, adequate pulp volume, and good sensation. (K) A healthy volume of regenerated soft tissues with faint scars was seen on the palmar aspect of the finger pulp. (L) The nail grew adequately dorsally, albeit with some hooking towards the front and medially due to the impact of the initial injury.

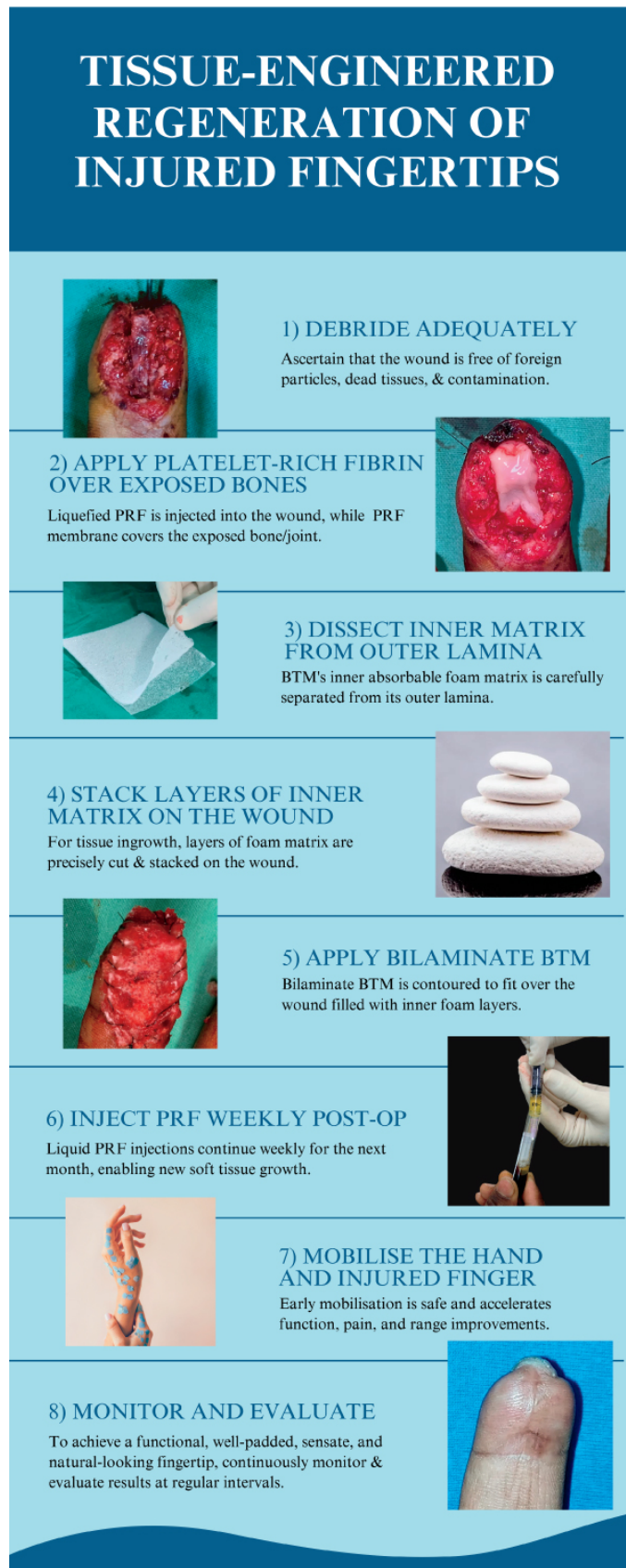


Figure 3: A schematic diagram of the tissue-engineered steps required to successfully regenerate an injured fingertip.

Discussion

Fingertip is the most distal region of a finger, and includes soft-tissues, nails, and bones located beyond the distal phalangeal base, where the long flexor and extensor tendons get inserted. They are highly mobile and sensate, allowing the hand to perform several complex functions and fine movements. Ample volume over the pulp and tip of the finger allows the hand to pinch and grasp correctly. Fingertip reconstruction requires the proper restoration of length, volume, and sensation^[2,4]. Still, terminalisation (partial amputation) of the exposed bones with primary closure of the remaining finger length is a common practise around the world. Although technically simpler, it results in permanent disability and should be avoided if possible.

Reconstructive flap surgeries preserve the skeletal length of the injured finger by covering it with viable soft-tissues. Various flaps are used to procure tissues from the same finger (v-y advancement, moberg, neurovascular islanded), adjacent finger (cross-finger pedicle), palm (thenar), abdomen/groin, or toes (microvascular toe pulp)^{1]}. A cross-finger pedicle flap is commonly used to treat large palmar defects like this one. However, lack of tissue bulk, decreased sensation, stiffness, double surgeries, and dorsal-on-glabrous skin problems remain significant concerns^[1,2]. Major microvascular reconstructions necessitate a sophisticated hospitalised setup, which is lacking in many parts of the world.

Healing by secondary intention and dressing changes remains an appealing alternative to reconstructive surgery, particularly where the bones or joints are not exposed^[2]. Some surgeons successfully added semioclusive dressings as an artificial barrier even in cases with exposed bones^[5]. While it is much more beneficial for young children, it has proven to be a low-cost, simple, and successful therapy for all ages^[2,5]. It does, however, necessitate significant patient participation, comprehension, and compliance, and its success in uneducated patients remains a challenge. Previously, an author described a similar fingertip injury that involved palmar soft-tissues but did not expose the bone or joint. Although it was successfully treated with ultrasound treatments and second intention healing with aesthetically acceptable results, the palmar soft-tissue development was inadequate^[2].

Earlier, some authors explored the possibility of fingertip reconstruction with biomaterials. Success was evaluated both by two-stage approaches for large fingertip defects and one-stage approach for small defects^[6,7]. Despite volume loss and sensory deficits observed during follow-up, patients reported overall satisfaction with fully functional hands^[7]. Nonetheless, fingertip reconstruction with biomaterials had significant limitations that limited their widespread use, including insufficient pulp volume, sensory deficit, and prolonged recovery time^[3].

These concerns were also evident in the case described here at first. Volume loss and sensory deficits were observed after using the bilaminate BTM and relying solely on tissues regenerating from the wound edges (Figure 1E). The solution emerged from previous research, in which a novel method combining platelet-rich plasma (PRP) injections with BTM application regenerated sufficient soft-tissues over exposed skull-bones. In that case, platelet-derived growth factors and cytokines promoted fibroblast migration and capillary ingrowth through BTM, reducing the final defect to one-third of its original size^[8].

Previous research discovered that growth factors and cytokines secreted by activated platelets stimulated cellular processes required for new tissue development, such as migration, attachment, proliferation, and differentiation. They healed nerve

injuries and reduced sensory deficit, numbness, and neuropathic pain in patients with digital nerve crush injuries, indicating their benefits in improving fingertip sensation^[9]. PRF is a newer method of isolating PRP that does not require anticoagulants and has strong healing properties. PRF induced a higher rate of fibroblast migration and released higher concentrations of several autologous growth factors and cytokines than PRP^[10].

Conclusion

Tissue-engineered reconstruction, which combined stacked-up biomaterial with PRF injections, effectively and safely treated a severely crushed fingertip. Figure 3 depicts an infographic of the procedure's pathway. This innovative procedure successfully restored finger pulp volume and sensation while preserving finger length, preventing disability, and producing a fully functional fingertip.

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Conflicts of Interest

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